Antimalaria Measures for the Protection of Military Personnel in Puerto Rico and their Applicability to Civilian Malaria Control[1]

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INTRODUCTION

MALARIA is a disease of primary interest to civilian health authorities, military commands, and to the general public in Puerto Rico. As a civilian problem, it is one of the leading causes of death and probably most common among the disabling, preventable diseases. Among civilians, it is a public health and economic problem more because of the illness it causes than because of fatalities since there are generally from fifty to several hundred cases of malaria for each death. However, when more reliable indices are lacking, mortality statistics are valuable as a crude measure of malaria morbidity. Although mortality rates fail to reveal many phases of the malaria problem, they do have comparative value in demonstrating the trend and cyclicity of malaria among a population group such as Puerto Rico's.

During the ten year period of 1930–1939, malaria ranked from fifth to seventh place among the leading causes of death. It was exceeded by only two other causes commonly regarded as preventable, namely, diarrhea and enteritis and tuberculosis.[2] In later years, malaria mortality in Puerto Rico has retained a similar rank.

Vital statistics records (Chart A) show a rising trend both in malaria deaths and in mortality rate over the 33-year period of 1910–1942, with a recent high of 125 per 100,000 in 1941. The pattern is one of irregular cyclicity, differing in this respect from the regular periodicity noted in many other places. In common with malaria everywhere, the disease in Puerto Rico is cyclical.

In view of the importance of malaria as a civilian problem in Puerto Rico, it is my purpose to present procedures, observations, and accomplishments in the current program of protecting military

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2. J. M. Henderson, Urban malaria in Puerto Rico. Puerto Rico J.Pub.Health & Trop. Med., 17:278–288, 1942.

forces in the Island and to interpret their value in the future planning and application of civilian malaria control.

In terms of financial expenditure, the Malaria Control in War Areas program is the major phase of the emergency health and sanitation activities of the United States Public Health Service. The area served by the MCWA Headquarters in San Juan is contiguous with the Army and Navy Commands, extending from French Guiana on the east to Cuba and Jamaica on the west. This program is concerned solely with furnishing protection to the Armed Forces and their civilian components or, in exceptional circumstances in continental United States, to those civilian employees of industry in malarious areas who are engaged in such critical activities as the production of ships, airplanes, and munitions.

The program in Puerto Rico, initiated in March 1942, is conducted in coöperation with the Insular Health Department, the Army, the Navy, and the Coast Guard; it is an expansion of limited work commenced by the Insular Health Department in December 1940 at one military post and extended, subsequently, to several others. While assistance is given and work is performed on Army-owned land within the reservations, MCWA activities are concerned mainly with extrareservation areas lying within a two mile radius of military housing in the posts and bases. Incidental protection is also given to approximately fifteen thousand native and continental civilian workers, employed by the Army and Navy in the construction and operation of military bases.

Owing to the larger number of Army personnel in Puerto Rico, as compared with the Navy and Coast Guard, and to the smaller land acreage of Army reservations as compared with Navy bases, MCWA is concerned principally with protecting the Army. Approximately 90 percent of the malaria mosquito breeding places affecting Army forces are located outside of the reservations.

When the MCWA program was initiated, conferences were held with the Commissioner of Health of Puerto Rico and his staff to establish policies that would check most effectively the rising rate of malaria among the Armed Forces. Because the problem was acute and the existing Insular Health Department program was inadequate, it was agreed that the control of the malaria vector, *Anopheles albimanus*, within mosquito flight range of military installations should be the direct responsibility of MCWA. Potentially, this arrangement also made possible more effective civilian malaria control, as it relieved the Insular Health Department of at least one of the many emergency demands on its personnel and financial resources

that were being diverted from, and impeding progress on, the geographically larger problem of island-wide civilian malaria control. The Bureau of Malaria Control of the Insular Health Department has rendered invaluable assistance by loaning some of the personnel and equipment that it had assigned to military malaria control prior to initiation of the MCWA program. In effect, MCWA has operated as a special service branch of the Army and the Navy, largely relieving their engineers of one of the four basic sanitary utilities of each post, namely, control of malaria mosquitoes.

Another administrative arrangement, which facilitated effective malaria control operations in Puerto Rico and the rest of the Caribbean area, was the establishment, by the Commanding General, of the Antilles Department Army Malaria Board in December 1942. This Board is composed of a senior member—the author of this paper—and two field officers representing the District Office of the United States Engineers and the Office of the Antilles Department Surgeon, respectively. The Board reports to the Commanding General, and its close relationship with the Assistant Chief of Staff, G–4 in particular, has ensured favorable consideration of the over-all requirements of antianopheline operations. Under the aegis of the Board members, progress has been achieved in integrating the activities of the two principal agencies engaged in Army utility operations, namely, the United States Engineer Department and the MCWA. This has been accomplished chiefly through establishment of direct operating relations between the field and staff officers of these two organizations.

PROJECT OPERATIONS

Due to the demonstrated inability of chemical prophylaxis to interrupt malaria transmission, the method of attack on malaria among military personnel has been limited almost wholly to anti-anopheline measures, specifically against the species *Anopheles albimanus*. These comprise measures against (a) the imaginal or adult stage and (b) the larval stage.

Anti-imaginal measures are concerned with mosquito proofing of barracks and quarters, supplemented by the periodic spray killing of mosquitoes that have penetrated through barrier screens into housing facilities. This phase of the work has been performed solely by the Army at the Department and Post levels with minor consultative assistance by MCWA. For this reason, only limited mention is made of anti-imaginal activities, but it should not be implied that they were unimportant in the over-all program.

Antilarval measures have been largely limited, by choice, to drainage and Paris green larviciding. As the breeding areas are chiefly in the two-mile extrareservation flight zone and progress by the Army in the control of intrareservation breeding areas has been limited until very recently, virtually all of the antilarval work responsible for military malaria reduction over the past year and a half has been prosecuted by MCWA. It should be noted, however, that drainage of extensive scope is under way by Army engineers around one post on a joint MCWA-Army project. Benefits from this work are now beginning to be felt. Future benefit will also result at two other posts when intrareservation drainage under way is completed by Army engineers.

Two types of antilarval projects are operated by MCWA in Puerto Rico. The first, which is called the Larvicidal and Minor Drainage Project, is carried on at all posts and bases having a significant number of cases of malaria and a military population large enough to justify extensive antilarval activities. No project has been operated where the military population is under a thousand. Larvicidal activities comprise principally the weekly application of Paris green dust by hand- and power-operated blowers on the breeding areas. The hand blowers and the smaller power blowers are carried by laborers who walk alongside or through the breeding areas, while the larger power blowers are mounted on oxcarts or small trucks. Both types of blowers have an effective radius of application ranging from 50 to 500 feet. On two projects, breeding places in mangrove swamps are inaccessible to men and vehicles and are too large to dust from the edges, therefore two low-flying, slow-speed airplanes are used.

The Paris green is diluted with hydrated lime or calcium carbonate in proportions ranging from 5 percent by weight for hand dusters to 20 percent for airplane dusting. It is applied to the breeding area at rates varying from one half to one pound of Paris green per acre (5 to 10 pounds of mixed dust per acre). Paris green is a stomach poison and must be ingested to kill the mosquito larva. Following application, it generally floats on the surface of the water long enough to be eaten by anopheline larvae, which are surface feeders. When applied at these dosage rates, it has little killing effect on the common obnoxious species of mosquitoes that feed principally on the bottom. A minimum of 25 Paris green particles may be found floating on each square inch of water surface, when applied carefully and at the recommended rate. Under these circumstances, from 90 to 99 percent of all but the youngest anopheline larvae are killed.

The total area of breeding places in MCWA control zones, in which production of *Anopheles albimanus* occurs at some time during the year, materially exceeds 10,000 acres. The acreage is so large because of the adverse location of several posts, which are surrounded by irrigated sugar cane lands, mangrove swamps, wet pastures, marshes, and man-made breeding places. Fortunately, due to the predilection of *Anopheles albimanus* for temporary water as a breeding place, the scattered distribution of projects over the Island, and the great local variations in rainfall and irrigation, only a minor fraction of the total area in which breeding occurs causes trouble during any given month or week. Currently, the consumption of Paris green is at the rate of 8,500 pounds monthly, or 11,330 acre treatments, at an average rate of 0.75 pounds per acre. Since Paris green is applied weekly, this represents an average of only 2,800 acres of breeding surface treated each week. The average treated in any given week during the current period may range from 2,000 to 3,500 acres, which figures would approximate 4,000 acres per week if it were not for extensive drainage already accomplished.

The term "minor drainage," as used in MCWA projects, signifies drainage maintenance and light drainage construction. Usually, Paris green can be applied in open marshes and pasture lands only during the early morning hours before the trade winds become too strong. During the rest of the day, the larvicidal crews carry on light drainage and clearing to make some breeding areas accessible for larviciding and to eliminate others as breeding places. This work comprises making access pathways, cutting brush around the edges of swamps and marshes, removing aquatic vegetation, cleaning and straightening open ditches, filling low places, cleaning pond edges, and digging new shallow ditches. Some projects of this type also have from ten to fifty men employed full time on work that is intermediate between "minor" and "major drainage," consisting largely of stream reconditioning. Breeding may be eliminated from many small brooks or "quebradas" by straightening alignment, sloping and sodding ditch banks with Bermuda grass stolons, installing concrete curtain walls at the grade line and rubble masonry on the outside faces of curves to control storm-water erosion.

Eight area-wide projects of this type have been operated in Puerto Rico in 1942 and 1943, each protecting from one to four military installations. The largest number in operation at any one time has been six, as some posts have been closed and others opened within the period.

The other project type is called "major drainage." Such projects

are initiated at posts where investigation has determined that extensive heavy engineering construction is necessary to drain breeding places in which *Anopheles albimanus* production cannot be effectively controlled by larviciding. The greater part of this construction has been performed with hand-labor gangs, supplemented by relief-labor gangs. Production per man hour has averaged about one third that of regularly employed MCWA labor. "Major drainage" projects have been operated at four military base areas in Puerto Rico.

Potentially, much of this work could have been accomplished more rapidly and more economically by the mechanical methods used in peacetime. However, manpower resources have been more than adequate, but construction equipment available in Puerto Rico is largely worn out and subject to frequent breakdown. Often-times a year elapses between order and delivery dates for critical repair parts from the continent, as emphasis has been placed on the conservation of construction equipment for use in combat zones. Fuel shortages have been acute. These factors led to the selection, wherever possible, of hand-labor methods.

Administratively, it has been found desirable to operate major drainage as an independent activity under separate resident supervision, even though a larvicidal and "minor drainage" project may be operating in the same area. Larviciding is essentially a tactical operation, involving a shifting attack directly against a living enemy, in this case, *Anopheles albimanus*, over large land areas. This mobile attack is controlled by daily intelligence reports in the form of larvae and adult mosquito collections; the work is recurrent and perpetual. On the other hand, heavy engineering construction is nonrecurrent, fixed in location, and limited in duration. Selection of the work as to location and design is made before project operations start and, once initiated, is subject to revision through the influence of physical rather than biological factors. Since the two projects require not only differing supervisory arts and skills but also a basic difference in mental approach at the project supervisor level, the effectiveness of each project will suffer where joint local management is attempted, unless malaria control engineers, thoroughly experienced in both heavy construction and biological campaigns, are available. These were not found among local candidates in Puerto Rico.

The principal types of "major drainage" comprise (a) wide cross-section, open, wet, sea-level canals for marsh and lake drainage near the seacoast; (b) open-ditch systems lined with precast concrete

inverts with and without slide slabs, and with ditch banks stabilized with Bermuda grass stolons; (c) creeks subdrained with large diameter open-joint concrete pipe; (d) wet pasture lands and seepage areas subdrained with small diameter open-joint concrete pipes in closed ditches; and (e) a permanent concrete pumphouse, discharging at sea level, with a capacity of 30,000 gallons per minute, which serves a gravity collecting system of large cross-section open canals draining 400 acres of mangrove swamps and low pasture lands. This system is protected by dikes and tide gates from river flood waters and high tides.

Peak employment on the over-all MCWA program has approximated 850 men, averaging about 300 in 1942 and 650 in 1943. The maximum number employed by MCWA on major drainage in Puerto Rico was approximately 150 men in 1942 and 350 in 1943, including overhead and concrete products plant employees.

Total MCWA expenditures in calendar year 1942 were approximately $200,000, while those for calendar year 1943 approximated $400,000; 1944 expenditures should be markedly reduced by the anticipated completion of virtually all "major drainage" by mid-year and the reduction in larviciding operations through drainage.

The total cost of all permanent drainage and filling accomplished for military base malaria control through 1943 cannot be computed, as MCWA, Insular Health Department, Army, WPA, and PWA participation is involved and the first work was initiated in the beginning of 1941. In the case of relief work drainage, it is also difficult to apportion expenditures between malaria control and social welfare, but the estimated contract value of functioning drainage systems ranges from $50,000 to $500,000 for each of the four posts involved. The aggregate cost is estimated at less than one percent of the physical investment in Army and Navy bases and their related facilities in Puerto Rico. This is an amazingly economical expenditure, especially when consideration is given to the adverse location of many installations, the absence of heavy investment in fixed fortifications which would dilute this percentage, and the acuteness of the malaria problem. However, even this modest investment is only partly chargeable to malaria control, as the most costly permanent drainage project was to correct man-made breeding places, created incidental to military construction and hence a compensatory element of work authorized for other purposes. Also, much of the remaining drainage is multipurpose in benefit.

The area of the anopheline control zone of individual MCWA projects varies from 7,000 to 20,000 acres. As the area of a circle

with a two-mile radius is 8,000 acres, only those posts located within two miles of the sea have smaller control zones. These smaller project areas approximate in size the area of control needed for malarious coastal towns, such as Salinas and Santa Isabel. The largest project of 20,000 acres protects two near-by bases, one of which has scattered housing areas. This probably exceeds in size the combined control zone that would be required for the City of Ponce and Ponce Playa.

PROGRAM PLANNING

The experience of Dr. Earle and his associates on an antilarval malaria control program in the small town of Salinas, Puerto Rico, has been of particular value in planning MCWA malaria control.[3] As may be recalled, the initial antimalaria program at that location began in 1930 and lasted six years. Antilarval measures were expanded and intensified each year, and their effect on the *Anopheles albimanus* population and human malaria incidence in the urban area was recorded. Mosquitoes were collected by means of numerous portable screened cages, known as the Caribbean animal-bait trap. In each cage, a small horse or calf was placed overnight to attract female mosquitoes seeking a blood meal, and the number of female *Anopheles albimanus* per trap per overnight collection was used as an index of the malaria mosquito population.

As will be seen from Chart B, the high plateau of malaria incidence at Salinas was apparently unaffected during the first four years of control work. Although the bait trap index was only 3 in the first year of the program and only 1.9 during the second semester, or "malaria season" of that year, it was not low enough to control malaria, which did not decline sharply until the fifth year, when the average annual index fell to 1.2 and the index for the "malaria season" semester was only 0.9. These figures represent collections from traps near the center of the control zone and hence are an index of exposure of the urban human population to malaria mosquitoes.

Throughout the fifth year of control (1934), only 169 cases were reported, which number compares with 730 cases during the preceding year and a minimum of 470 cases annually in the six years previous. There is reason to believe that the decline in primary malaria in 1934 was even greater than these figures indicate. In other years, most cases of malaria were reported during the second semester because the principal malaria season is in the fall. However, of the 169 cases reported in 1934, 121 were in the first half and only 48 during the second half of the year. These 48 cases compare with 396 cases for the second half of 1933, a decline of 88 percent. In view of the large number of cases reported in the fall of 1933, the presumption is that many of the 121 cases noted during the following first semester of 1934 were recurrences. The decline was sustained in 1935, with only 52 cases reported for the year and 32 for the second semester, a reduction of 93 percent from 1933 in each instance. Although statistics are not available, the Chief of the Malaria Bureau of the Insular Health Department advises that this reduction has been sustained in subsequent years. Thus, there is sound basis for accepting an average central trap index of approximately one female *Anopheles albimanus* as the level of malaria interruption in a locality with the malariogenic qualities of Salinas.

Several lessons are to be gained from the Salinas demonstration. As it is not uncommon to encounter thousands of breeding places in a project control zone, with a precontrol central trap index in the hundreds, the most obvious lesson is that antimosquito operations must be of the greatest possible intensity, that they must be

3. W. C. Earle, The relation between breeding area, *Anopheles albimanus* density, and malaria in Salinas, Puerto Rico. South.M.J., 30:946–950, 1937.

Thatched animal-bait trap used to collect *A. albimanus*

concentrated usually around a small number of population centers at any moment in order to be prosecuted with the required intensity, and that halfway measures are wasteful, futile, and without benefit.

Another lesson is the yardstick furnished by animal bait trap collections of *Anopheles albimanus* imagoes in the planning, design, and management of antilarval project operations. Had it not been for this lengthy and carefully supervised experiment, we would have been wholly without an aiming point in projecting the current program. This does not imply, however, that an average trap collection figure of one should be arbitrarily adopted as a safe index. Modifying factors are involved. While their precise values are not known, some adjustment can be made in specific situations. In the first place, the safe *albimanus* index is influenced primarily by the malaria level and, more particularly, by the gametocyte level among the people on whom malaria mosquitoes feed. Since infection in the mosquito must be obtained from a human source, fewer malaria mosquitoes are needed to maintain malaria if many human carriers can be bitten. Secondly, the safe index is equally affected by the accessibility of human blood meals. If it is difficult for malaria mosquitoes to bite humans, fewer mosquitoes are infected and fewer people are bitten by the infected mosquito. These are the principal factors. There are also many secondary ones, too intangible to evaluate in terms of mosquito indices. With regard to the two primary factors, Salinas furnished optimum conditions for malaria transmission, and it is believed that a safe index at other places in Puerto Rico would probably never be lower and generally higher. Salinas, in common with the rest of Puerto Rico, has few or no screened dwellings and offers a highly accessible mass blood meal. The malaria level was as high as in any other town in Puerto Rico, this being a major determinant in its selection for Earle's demonstration.

By contrast, all of the military population involved in the current program lived in screened buildings during the precontrol period and throughout the period of antilarval operations. Also, the general level of malaria among the civilian population in the vicinity of each post was, with one exception, markedly lower than at Salinans. For these reasons, an index of 5 was tentatively adopted as an aiming point on the MCWA military base program. In view of the opportunity for exposure of personnel to mosquito bites while outside of screened buildings, it was felt that maintenance of the *albimanus* population at this level would not eradicate indigenous malaria on the posts, but that it could be reduced to, and held at a minimal level, by reaching and maintaining an index of 5, or lower.

ANIMAL-BAIT TRAP COLLECTIONS OF ADULT *Anopheles albimanus*

The following charts show by months the progress made through antilarval activities in reaching and passing this objective. The plotted points represent average collections of female *Anopheles albimanus*, taken from four to eight animal-bait traps located within each Army reservation at or near the center of the control zone and in the immediate vicinity of military housing. They accordingly furnish an index of the exposure of military personnel on the posts to malaria mosquito attack. These traps comprise only a minor fraction of the total number of each project, the remainder being located at strategic places throughout the two-mile control zone for the purpose of measuring anopheline production in localized zones and determining the direction of ingress flights.

The four charts represent those posts that contributed to the overwhelming bulk of the malaria morbidity among Army personnel in 1941 and 1943 and at which trap collection records are available for a continuous period of one and one half years or more. None of the charts include precontrol collections, as the acuteness of the malaria problem at every post required prompt initiation and continuous operation of antilarval activities. Moreover, limited larviciding by the Insular Health Department and drainage construction relief agencies, under the co-sponsorship of the Insular Health Department and the United States Public Health Service, had preceded initiation of MCWA operations by from three to fifteen months at the first three posts. At the fourth, a more recent installation, no antilarval work was performed prior to initiation of MCWA operations. Thus the reduction in mosquito population, shown on these records, merely represents progress realized within the period of control operations, and it may be assumed that seasonal collections prior to control were materially higher.

Reduction realized within the control period may be attributed to a number of factors. Among the more prominent are: (a) gradual progress in the drainage of breeding areas that could not be larvicided effectively; (b) the cumulative effect of larviciding in reducing the number of egg-laying females; (c) the delayed arrival of urgently needed shipments of materials, equipment, and supplies; and (d) improved operating efficiency.

Chart C shows *Anopheles albimanus* collections at Post T, where two peaks occurred in 1942—the first in June when average collections reached 45 and the second, averaging 27, in November. The first was caused by heavy seasonal rains that intensified production in 1,500 acres of permanent marsh and temporary lowlands around

this post. The second and lower peak clearly reflects progress in control operations accomplished during the ensuing five months, as rainfall was comparable and biological conditions in Puerto Rico are more favorable to *Anopheles albimanus* production in the fall than at any other season. In spite of this, trap collections in January 1943 dropped to 3 and, subsequently, have averaged less than 2 over the past sixteen months. The early summer peak in 1943 occurred in July, when collections rose to 4 following the heavy seasonal rains, a reduction of 90 percent from the June 1942 peak. A peak of 4 was again reached in November 1943 as compared with 27 in the previous November. As a result of the completion of additional "major drainage" units since November 1943, we anticipate that even these slight rises will be suppressed farther in 1944.

Malaria cases reported from this post have been negligible throughout 1943. The rate has been so low there is reason to believe that no transmission of malaria has occurred within the post, even outside of screened-housing facilities or in defectively mosquito-proofed quarters. The few scattered primary cases reported may be attributed to exogenous cases resulting from overnight and week-end leaves among native troops or among small detachments assigned temporarily to other locations.

Chart D shows *Anopheles albimanus* collections at Post B, located in another part of the Island. Here, with partial control measures, a peak of 98 occurred in May 1942. In November, six months later, the next peak of 85 reveals some progress in control operations, as collections in comparison traps, where control work is not being practiced, consistently reflect a larger *albimanus* population in wet fall months than in the wet months of other seasons. These collections compare with peak collections of 4.5 in July 1943, and 20 in November 1943—reductions of 95 percent and 73 percent, respectively. Collections were below 5 for the six-month period March to August 1943, and again for the five-month period, December 1943 to April 1944. During the last three months, collections have not exceeded 0.4. Several units of "major drainage," which were planned in August 1942, have been completed since December 1943. Average collections within the limits of zero and five are anticipated in all future wet seasons for the duration of the war.

Chart E shows *Anopheles albimanus* collections at Post L, located on the south shore of the Island. At this post heavy seasonal precipitation, occurring in the fall when the biotic potential was highly favorable for *Anopheles albimanus* production, was responsible for a sharp rise in collections during October, November, and December

1942 to a peak of 72 at the end of the three-month period. In the following year, as a result of more adequate larviciding, further progress in "major drainage," and a wider spacing of seasonal rains in the fall months, peak monthly collections were held to a maximum of 6 in November 1943, a reduction of 92 percent from the previous year. By the end of the first week in December, additional units of major drainage, which had been under construction for a year, were completed. These comprised the dewatering of a large semipermanent brackish water swamp with dense stands of second-growth black and white mangrove and cattail (*Typha angustifolia*). Residual production from this swamp was sufficient to partially nullify the excellent control realized in the rest of the control zone. This was due to the incomplete kill realized with larvicides, when applied either by airplane or from the ground, and the high intensity and extensiveness of breeding. Had this drainage been completed by the first of November, it is doubtful whether a rise in November collections above the one to three level would have resulted.

As human population was reduced to a minimal level, all antilarval work was suspended on December 10, 1943, in accordance with a request from the Antilles Department Headquarters. Lack of rain in December and the two weeks interval between ovum and imago at this season of the year resulted in low collections through December in spite of the cessation of larviciding early in the month. However, in ensuing months, a contraseasonal rise reflected the stoppage of control work even though a sustained drought and seasonal biological factors unfavorable for *Anopheles albimanus* production persisted. This is evident if comparison is made between 1943 and 1944 collections for the months of January through April.

At the other three posts, there is presumptive evidence that average collections of five are low enough to interrupt the local transmission of malaria among the military population. The exception was a slum village of nearly four hundred people, where a single collection of thick blood films among an all-age group returned 12 percent positive. This community was located within one quarter of a mile of military housing but was moved at moderate expense to a more suitable location.

At Post L, the malaria situation was more comparable to that at Salinas before Earle's program. Not only was the thick blood-film index higher within *albimanus* flight range of the post (it varied from 20 to 40 percent) but also the malaria density or number of cases within a mile of the post was several times greater because of the higher rate and the near-by congested rural slum communities.

At this post, the average malaria rate among the military personnel was reduced at least 50 percent in 1943 by comparison with 1941 and 1942, but this resulted largely from reduction during seasonal periods when trap collections varied between zero and two. In other posts, malaria showed no tendency to rise even in the presence of slight sustained increases in trap collections or larger temporary increases once the disease had been suppressed effectively among military personnel. Notwithstanding, at Post L the malaria rate responded sharply to minor increase in collections, such as in May and June 1943, and to the larger but more temporary increase as in November 1943. The rise in malaria was generally first manifested six weeks after the first sharp weekly rise in trap collections. Whether these infections were contracted from the limited number of mosquitoes entering casually into those sleeping quarters that were not adequately mosquito-proofed and sprayed, or whether the biting occurred in defective buildings and outside of buildings within the post limits is not known. The latter was presumably the case. Post officers reported that malaria incidence among night guards and sentries was substantially higher than in the balance of the command.

Experience at this post indicates a safe upper limit of animal-bait trap collections as not greater than two.

Chart F shows *Anopheles albimanus* collections at Post O. Construction of buildings was substantially completed early in July 1942 and it was activated in that month. An MCWA area engineer was assigned July 16, 1942, but the first two weeks there were occupied with recruiting and training labor. August 1 marks the approximate starting date of field operations in larviciding, "minor drainage," and related entomological inspection activities. *Anopheles albimanus* production at this post, located in meadow land at the junction of two rivers in the interior of Puerto Rico, occurred principally in a converging network of more than 100,000 feet of "quebradas," or brooks, and small creeks, in the furrow ditches of abandoned cane fields on the post itself, and in numerous seepage areas in the stream valleys. Heavy breeding was also found in the two rivers at times of low flow. At the other three posts, more than 90 percent of the breeding places were outside of the reservation, but at Post O, they were divided almost equally. Although military housing was located near the camp boundaries in all directions and the control zone accordingly extended nearly two miles beyond the reservation boundaries, housing facilities were dispersed over a 900-acre tract. Due to the flatter topography of the camp side, the density of breeding places per unit of land area was substantially greater within the reservation than outside of it. For this reason, MCWA project activities during the first six months of operation were concentrated largely within the reservation, although some attention was given to the more distant extrareservation control zone.

In these first six months it was found necessary to use most of the labor gangs on clearing work. High grass and thicket growth were cut from the banks and the channels of the network of small streams, which were thus made accessible to larviciding crews. Similar work was necessary in the seepage areas and old cane fields but, in spite of project activities, collections were high throughout 1942 and in January 1943. Two peaks were recorded, one of 35 in August 1942, and a second of 33 in November.

The malaria rate at this post was high in 1942 but collapsed subsequently and was negligible through 1943 and the first part of 1944. Beginning with February 1943, collections of *Anopheles albimanus* have been below 5 for fifteen consecutive months. Average monthly collections did not exceed 0.6 in the first four months of 1944.

Minor seasonal rises occurred in May, July, and October 1943, but malaria incidence here did not respond. The seasonal peak of 3 in July 1943, compares with 35 in August 1942, a reduction of 94 percent; a seasonal peak of 3 in October 1943, compares with 33 in November 1942, a 91 percent reduction. As with Post B and Post T, it is questionable whether any indigenous primary cases of malaria have occurred at Post O since 1942. At this last place mosquito proofing has been of limited benefit in protecting military personnel from malaria. Practically no tongue and groove lumber was available in Puerto Rico when the post was built, and the square-edged dressed lumber used was green and low in quality. Nearly every building had scores of wide cracks between floor boards; the side walls had many openings, and doors would not close properly. It was not possible to begin correcting these defects until June 1943; the work was not substantially completed until January 1, 1944.

MALARIA REDUCTION

Data on malaria incidence is more available and more reliable on the current program than on most peacetime programs of civilian malaria reduction. This compensates, in part, for the many war-induced physical handicaps to operations. Weekly and monthly malaria morbidity records for military personnel provided a sensitive index for the over-all guidance of antilarval operations. The controlled character of the protected population ensures the adequacy

of these records; accordingly, the collection of other data on human malaria was not essential for effective malaria control operations.

Unfortunately, these data cannot be revealed and it is not possible to compare quantitatively in this paper the relationship between malaria incidence and animal-bait trap collections. However, on three of the four projects, results were not comparable with Earle's[4] experience at Salinas. In one project area in particular, malaria declined significantly and contraseasonally well in advance of extreme reduction in the *albimanus* population by control measures. At three projects, the transmission of malaria appeared interrupted when average collections of *albimanus* were maintained below a ceiling between five and six times higher than at Salinas in 1934 and 1935. This occurred during a period of general, but lesser, cyclical decline in civilian malaria in Puerto Rico.

This experience focuses attention on basic differences between the two demonstrations. None of these three MCWA projects was near Salinas in location. When work was started, the seasonal *albimanus* population was many times greater than at Salinas, but records indicate that civilian malaria incidence was materially lower in the MCWA project areas, both in rate and spatial density. Moreover, while towns and villages were in the one- to two-mile zone around each project, population in the zero to one-mile zone was rural and sparse for Puerto Rico. Thus the density of near-by gametocyte carriers, which presumably furnished the main reservoir of infection for the protected populations, was relatively low. By contrast, the reservoir of infection at Salinas was not only high but was also contained largely or wholly within the protected population itself. These differences in number and accessibility of gametocyte carriers offer one explanation for the higher "threshold of sanitary importance," as expressed in terms of mosquito indices.

A probable reason for the decline of malaria incidence at this one project, prior to extreme suppression of the *albimanus* population, was the beneficial effect of anti-imaginal measures. Although these were in effect when malaria incidence was at its height and before the initiation of extensive and intensive antilarval operations, they were intensified generally over the Island during the period of the MCWA program. Since the execution of anti-imaginal activities was decentralized, the effectiveness of application would naturally vary materially not only between projects but also for population elements within the individual project. The attack against the adult

4. W. C. Earle, *op. cit.*

mosquito was prosecuted with special vigor on this particular project concurrently with a substantial, but not extreme, reduction in the adult mosquito population accomplished through antilarval activities.

Differences in exposure of population elements within one project area, arising from the varying application of protective measures against adult mosquitoes, and the varying duties and customs of the individual person would also favor a gradual and irregular decline in malaria rate with progress in antilarval measures. In some population elements, which were protected to a high degree against adult mosquito attack, the incidence of primary malaria might disappear with moderate reduction in mosquitoes emerging from the larval stage, but malaria incidence among more exposed or more poorly protected elements might be unchanged. The resultant effect for the combined groups would be malaria decline. By contrast, the protected population on Earle's demonstration at Salinas was exposed relatively uniformly to malaria mosquito hazard because of the limited area of the town and the general absence of anti-imaginal measures.

The fourth project, on the other hand, was located near Salinas. Topography and malaria prevalence were comparable. While subject to the same seasonal and hydrologic influences, *Anopheles albimanus* production was substantially greater than at Salinas. Five or six villages with high malaria rates were located within a mile of the protected population, and one was within two hundred yards. On this project, malaria transmission was suppressed only when average monthly collections of *Anopheles albimanus* were reduced to 2, or lower. Malaria transmission appeared to recur whenever mosquito collections rose above this figure, even for periods of only one or two months. The results confirm closely the Salinas experience, particularly after allowance is made for supplementary anti-imaginal measures which were in effect.

APPLICATION OF MILITARY MALARIA CONTROL PROCEDURES TO CONTROL OF CIVILIAN MALARIA

One contribution of this program to the knowledge of civilian malaria control in Puerto Rico is that malaria can be controlled effectively and relatively quickly by antianopheline measures, and that this can be done simultaneously at widely scattered locations. At all but one post, control has been made effective in from six months to two years. In the exception, two and a half years were required, but here progress was abnormally delayed by shortages of

equipment. The significance of this experience in terms of civilian malaria control would seem limited at first glance, as the possibility of utilizing auxiliary anti-imaginal methods with the same effectiveness as they have been applied to a controlled, disciplined military population is remote. However, after making adjustment in trap collection standards for differences in malaria level between Salinas and project zones in other parts of Puerto Rico, where the malaria level is lower, there is reason to believe that antilarval methods alone have been developed adequately enough in this length of time for effective control. Furthermore, antilarval work could be prosecuted far more rapidly in peacetime, as this program has been handicapped gravely by wartime difficulties. Parenthetically, the five or six years required to accomplish malaria control at Salinas appears due more to its experimental character and to dependence on outside agencies for financing and performing drainage construction.

One important difference between the current military malaria program and civilian malaria control lies in the duration of the benefit. Some posts have been designed only for war occupancy, and the life of MCWA malaria control measures has been planned accordingly. At more permanent posts the need for conserving critical materials for the war effort has dictated the use of temporary antilarval measures, wherever possible. Larviciding has been relied upon to control most of the breeding areas, and drainage has been attempted only where larviciding is ineffective. Under these standards generally not more than 25 percent of the total acreage of breeding areas requires drainage.

On the other hand, civilian malaria control work, particularly around urban areas, should be designed for permanency where *albimanus* is the vector. As most permanent drainage construction has a minimum life of twenty years, it will be found more economical than larviciding. The drainage of from 75 to 90 percent of the total acreage of breeding areas may be indicated.

A probable cost of the work at Salinas was $100,000 to $300,000. Accurate figures are not available, as most of the drainage appears to have been financed by relief and reconstruction agencies and sugar centrals rather than at the expense of the Insular Health Department. A substantial part of this investment can be charged to agricultural benefit, as subdrainage and pumping improved the yield of existing cane lands and made others cultivatable and suitable for pasturage.

The cost of permanent malaria control around urban areas in Puerto Rico would probably vary from $100,000 to $2,000,000 or $3,000,000 per city. The higher figure would apply only to a large city, such as Ponce, having a large control zone and located in low, flat terrain with many breeding areas. Performance of permanent malaria control is indicated around urban rather than rural areas not only because of the protection it affords a larger population and because there are many more cases of malaria per square mile, but also because the average malaria mortality rates per hundred thousand people is slightly higher in urban than in rural areas of Puerto Rico.

While permanent malaria control may seem expensive at first glance, much of the cost is offset by other benefits. In relation to other municipal utilities, the cost may often be moderate. A $4,000,000 project to enlarge the San Juan water supply is under construction. The cost of a complete system would probably reach $10,000,000 to $15,000,000. Public water supply investment in terms of disease reduction yields limited benefit, as diseases carried by water in Puerto Rico are also conveyed in many other ways. In all but the smallest cities, an adequate system of paved streets and access highways is far more costly than a malaria drainage utility system. Adequate sanitary sewerage and sewage treatment are also often more expensive.

SUMMARY AND REMARKS

As is generally known, environmental diseases are of far greater relative importance in semitropical and tropical than in temperate areas. In Puerto Rico, among the diseases commonly regarded as preventable, diarrhea and enteritis—a filth-borne disease—ranks first in mortality, while malaria—insect-borne—is third. Due to their low fatality rates, morbidity is overwhelming in relation to nearly all other preventable diseases. Because these and other environmental diseases, preventable by sanitation measures, are generally the outstanding public health problems in other warm climate countries, sanitation has often been considered basic in tropical public health. In malaria control, this concept has resulted in many successful demonstrations in the form of concentrated attacks, most of which have been undertaken as prerequisites to other public health activities. In the Caribbean, the first malaria control program was at Havana, Cuba. This work was started about 1900 following the campaign to control the yellow fever mosquito and after 5,633 deaths had occurred from malaria in the decade 1891–1900. Parenthetically, this compares with 24,000 malaria deaths reported in Puerto Rico during the last decade. The number of

deaths in Havana was lowered to 444 in the decade 1901 to 1910 and to only 6 deaths annually in the succeeding four years.[5]

The work at Havana was followed by a malaria control program in the Canal Zone—too well known for repetition of detail—which made possible the building of the Panamá Canal. A more recent demonstration, small in scope, was the six-year program at Salinas, Puerto Rico, and the most recent of all was the successful program of *Anopheles gambiae* eradication in northeast Brazil in 1939–1940, following a fulminant epidemic that killed fourteen to twenty thousand persons in one year in the States of Ceará and Rio Grande do Norte, alone.

The eradication of *Anopheles gambiae* in Brazil was accomplished almost wholly by larviciding and insecticiding, due to the domesticated habits of this species. However, successful malaria control in Panamá, Cuba, Puerto Rico, and other Caribbean areas, where *Anopheles albimanus* is the vector, has been achieved chiefly by drainage and related physical construction. Key directing personnel on work of this type must be a rare combination of builder and scientist, with some of the "know how" productive ability of a Henry Kaiser and some of the scientific knowledge of a James Bryant Conant. Scientific workers must be an integral part of the tactical organization in the field, if their services are to be beneficial. Construction experience, resourcefulness, and initiative in accomplishment are vital. The program of attack must operate with flexibility and timing.

The current program in its fundamental aspects confirms the same basic principles of those earlier successful programs. While some advances have been made in technical procedures on the current activity, its principal contribution to civilian malaria control in Puerto Rico is as a successful demonstration which has again confirmed principles learned forty years ago in tropical malarial control. These include:

1. The concept of tropical malaria control as a task force operation against a living enemy, involving the same requisites of adequacy, timing and fluidity of attack, unity and competency of command as in human warfare, and the same certainty of defeat, if essential elements are missing.

2. A firm belief in the ultimate wisdom and the moral obligation to spend funds and effort to prevent rather than alleviate disease,

5. J. A. LePrince and A. J. Orenstein, Mosquito Control in Panama (New York: G. P. Putnam, 1916).

and to apportion general health funds in accordance with epidemiological principles.

3. Belief in the successful demonstration as the most effective and most lasting method of public health education.

4. The realization that programs of urban malaria control in tropical areas, where *Anopheles albimanus* is an extensive problem, cannot be prosecuted effectively by local health organizations but can succeed only when directed and operated by a task force group with specialized abilities and skills.

As noted earlier in this paper, the malaria problem in Puerto Rico, in terms of mortality, has been increasing over the past thirty-three years and is one of the leading causes of mortality, morbidity, and economic loss. Indicative of the lack of basic progress on malaria control is the malaria situation in the second largest city of Puerto Rico. As reported in a previous paper,[6] an annual average of 184 deaths from malaria was given for this urban area of sixty thousand people over the five-year period of 1934–1938, a mean rate of 302 per 100,000. The highest probable fatality rate was 2 percent and the lowest, 0.5 percent. Accordingly, an estimated 9,200 to 36,800 cases occurred annually. These figures represent normal endemicity and are not inflated by an epidemic outbreak, as the minimum number of deaths annually was 161 and the maximum was 222. As an estimated $50,000,000 to $100,000,000 in insular and federal funds have been appropriated to the Insular Health Department for health activities over the past thirty-three year period, some inquiry into the reasons for this lack of progress might be warranted.

It would appear that the principal reason is that so little has been done to prevent malaria along sound systematic lines. Among the civilian population, the story of permanent malaria control in Puerto Rico might almost be summed up in one word—Salinas—a successful and praiseworthy demonstration in a small town of three thousand persons. Even there, most of the cost of the work was contributed by other agencies. While this lends credit to the enterprise of malaria control workers, it emphasizes the lack of public health expenditures for malaria control. Due in large measure to ten years of work relief in Puerto Rico by FERA, PRERA, PRRA, WPA, and FWA, involving malaria drainage financed from 90 to 100 percent with federal funds administered by these agencies, impressive figures in scattered permanent construction throughout the Island might be prepared. This could be maximized by adding work performed for other pur-

6. J. M. Henderson, *op. cit.*

poses, which furnished incidental malaria control benefit, generally potential. Though inroads have been made on the malaria mosquito population at various places, there appears to be no other highly malarious town or city in Puerto Rico, comparable to Salinas, where malaria has been controlled.

One immediate cause has been lack of appropriations for malaria control. This year the Bureau of Malaria Control, comparatively speaking, is wealthy, with an appropriation of $175,000, or 3 percent of the $5,750,000 directly appropriated to the Insular Health Department from insular and federal sources for public health other than welfare. A substantial part of the Bureau budget is earmarked for services and drugs for medical care, not malaria prevention. Some provision is made for drainage maintenance and for limited larviciding work at various locations throughout the Island. The amount remaining for the direct prosecution of drainage construction is negligible. Due to war-time restrictions on construction, the budget for the current fiscal year may be adequate for such permanent work as can be undertaken, but prewar appropriations have been negligible and postwar appropriations are apt to be equally inadequate.

The more basic causes for the low malaria control appropriation do not include any lack of professional concept of basic tropical malaria control principles by personnel of the Malaria Control Bureau. The problem there is adequately understood. Nor is it due to lack of insular and federal funds for health services. While these five and three-quarter millions are insufficient for all of the public health services that might be advocated, basic preventive activities should be favored at the expense of other work.

Apparently responsible for inadequacy in appropriation for permanent malaria control is the traditional emphasis in Puerto Rico on curative medical care as a result of the prevalence of morbidity and the inability of the average individual to pay for private medical service. Expenditures in this field have directly and indirectly prevented the development of programs of preventive medicine. Another handicap to progress in tropical sanitation has been the influence of patterns of public health development in continental United States on public health organization in Puerto Rico. These have been designed largely to meet the problems of a temperate climate and the social and economic conditions within that area. They follow an era more than a century long, in which temperate climate environmental disease problems were reduced to a secondary level, and they conform to the dominant current public health needs in the continental area, not in Puerto Rico. The net

effect of these two influences has been a public health program which insures a perpetuation of the two principal environmental diseases.

This could be corrected with respect to malaria by increased appropriations for investment in permanent construction of proven malaria control effectiveness around urban centers in Puerto Rico. These funds might be obtained by diversion from palliative activities, increased legislative appropriation to the Insular Health Agency, or both. The estimated cost of "building out" malaria from every city in Puerto Rico is $20,000,000, only 5 percent of the $400,000,000 scheduled for public improvements under the Six Year Plan of the Insular Government. The entire program could be financed by earmarking less than four months' receipts from federal rum tax payments to the Insular Treasury, which are currently reported to be at the rate of $75,000,000 annually.

These funds could be efficiently expended if the program were (1) planned for execution over a ten-year period at an annual rate of $2,000,000; (2) assigned to a governmental corporation under the framework of the Insular Health Department but possessing the procedural exemptions of special Insular Public Works Authorities; (3) administered by a professional staff qualified in the science of malaria control and possessing executive ability and the art of accomplishment in the field of large-scale public works engineering; and (4) removed from political interference.

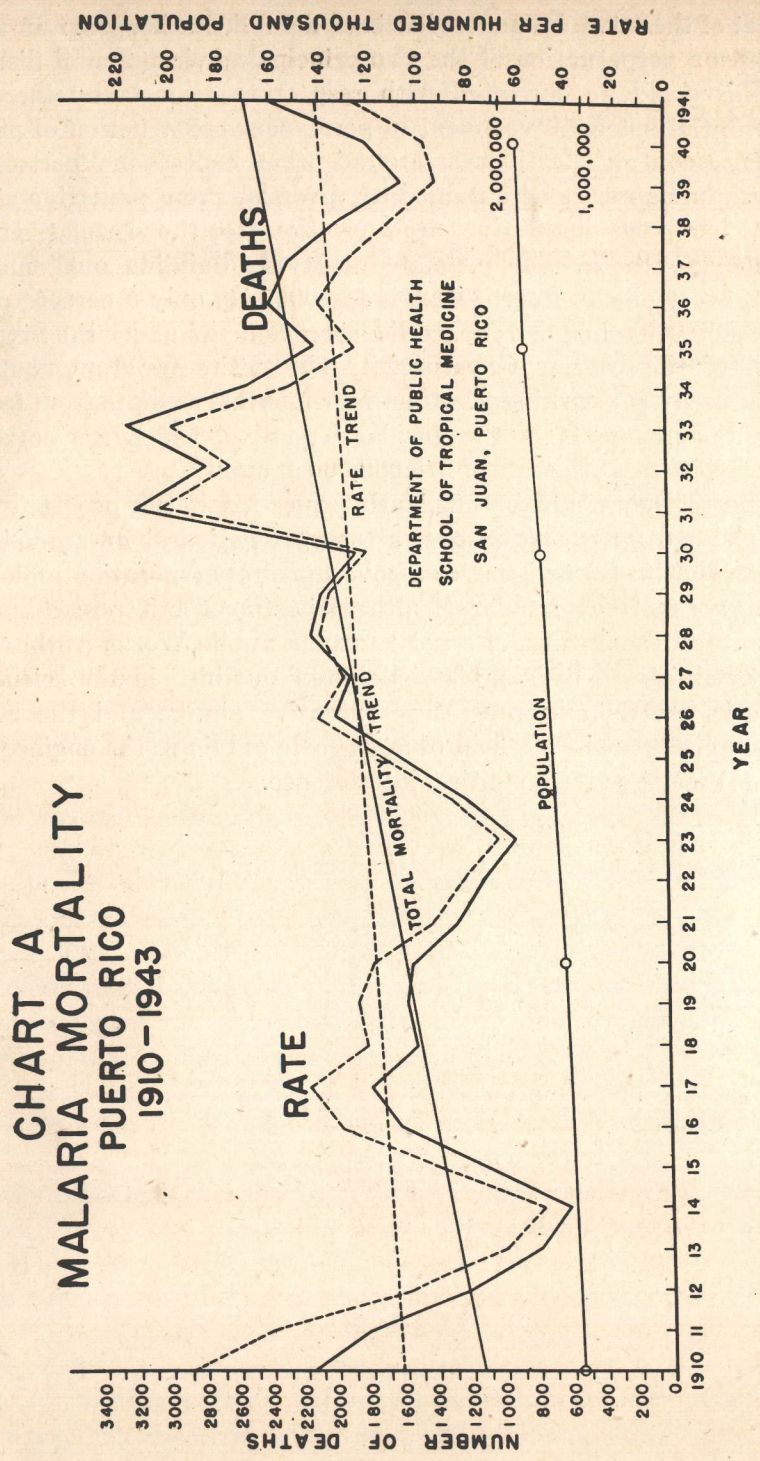
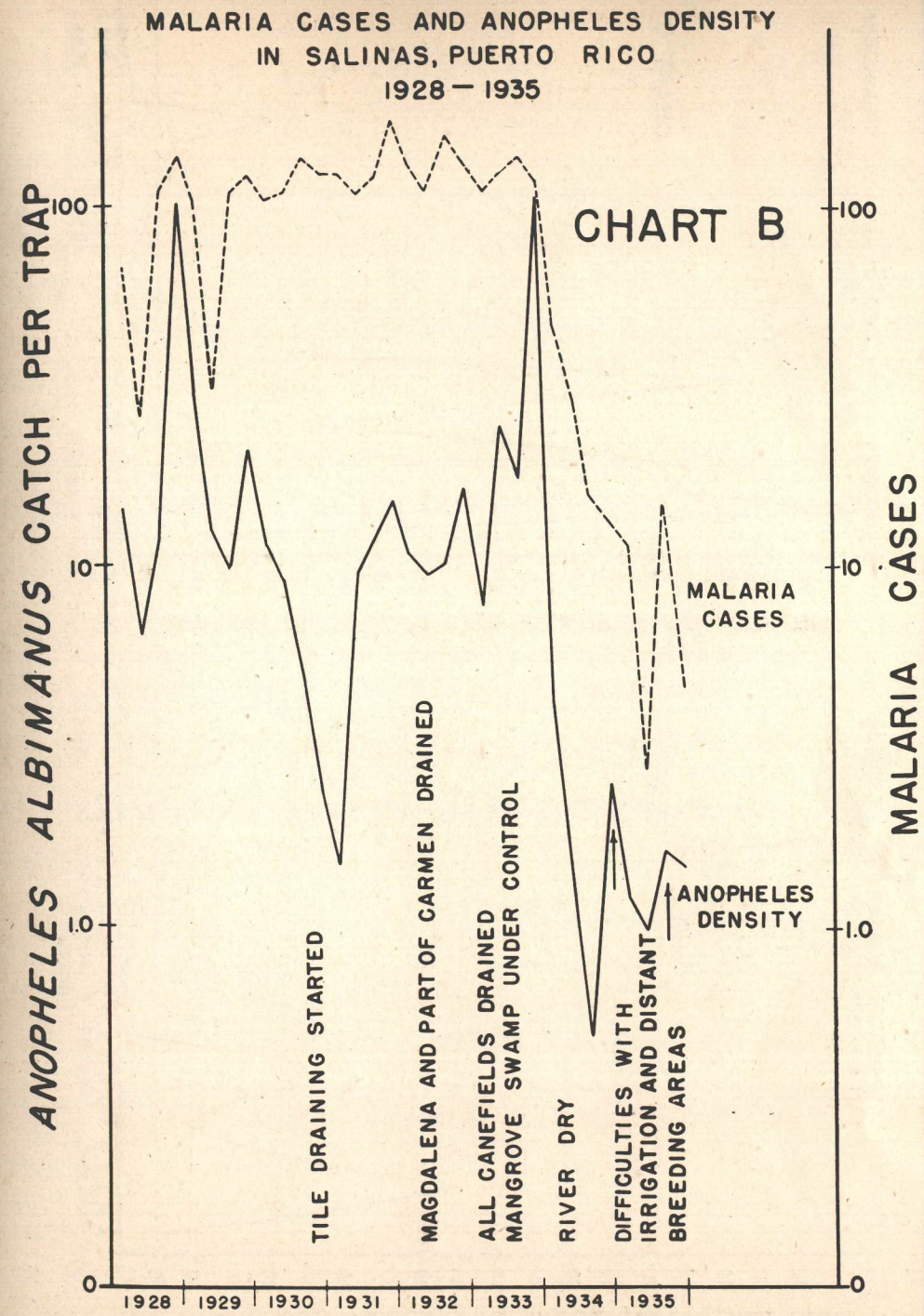


CHART A
MALARIA MORTALITY
PUERTO RICO
1910–1943
DEATHS
RATE
RATE TREND
TOTAL MORTALITY TREND
POPULATION
DEPARTMENT OF PUBLIC HEALTH
SCHOOL OF TROPICAL MEDICINE
SAN JUAN, PUERTO RICO
YEAR
NUMBER OF DEATHS
RATE PER HUNDRED THOUSAND POPULATION


MALARIA CASES AND ANOPHELES DENSITY
IN SALINAS, PUERTO RICO
1928 – 1935
CHART B
ANOPHELES ALBIMANUS CATCH PER TRAP
MALARIA CASES
MALARIA CASES
ANOPHELES DENSITY
TILE DRAINING STARTED
MAGDALENA AND PART OF CARMEN DRAINED
ALL CANEFIELDS DRAINED
MANGROVE SWAMP UNDER CONTROL
RIVER DRY
DIFFICULTIES WITH IRRIGATION AND DISTANT BREEDING AREAS

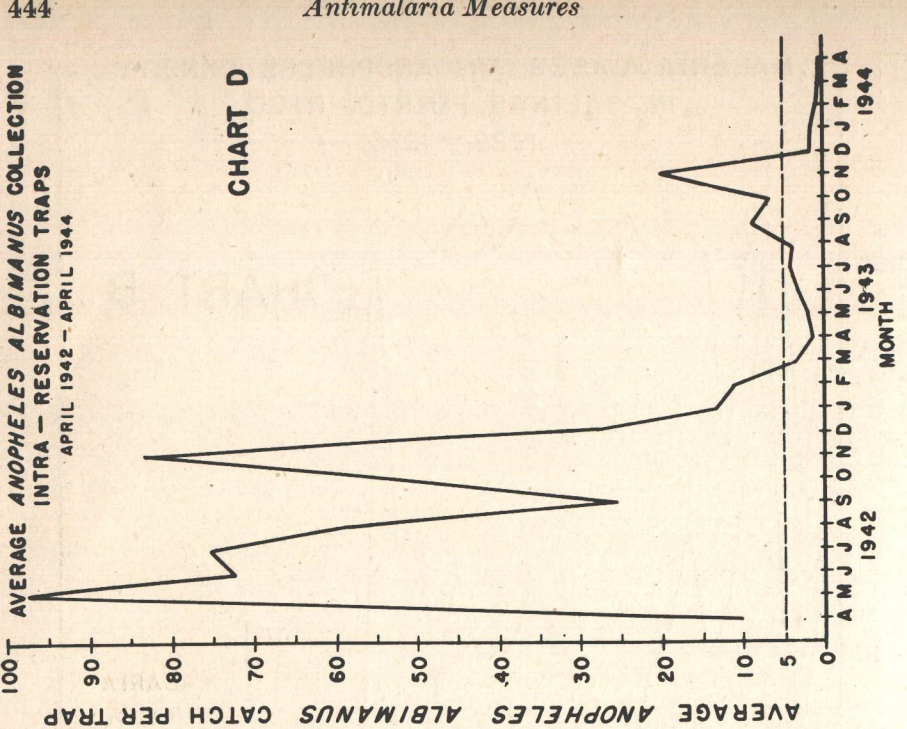


CHART D
AVERAGE ANOPHELES ALBIMANUS COLLECTION
INTRA — RESERVATION TRAPS
APRIL 1942 — APRIL 1944
AVERAGE ANOPHELES ALBIMANUS CATCH PER TRAP
100
90
80
70
60
50
40
30
20
10
5
0
A M J J A S O N D J F M A M J J A S O N D J F M A
1942
1943
1944
MONTH

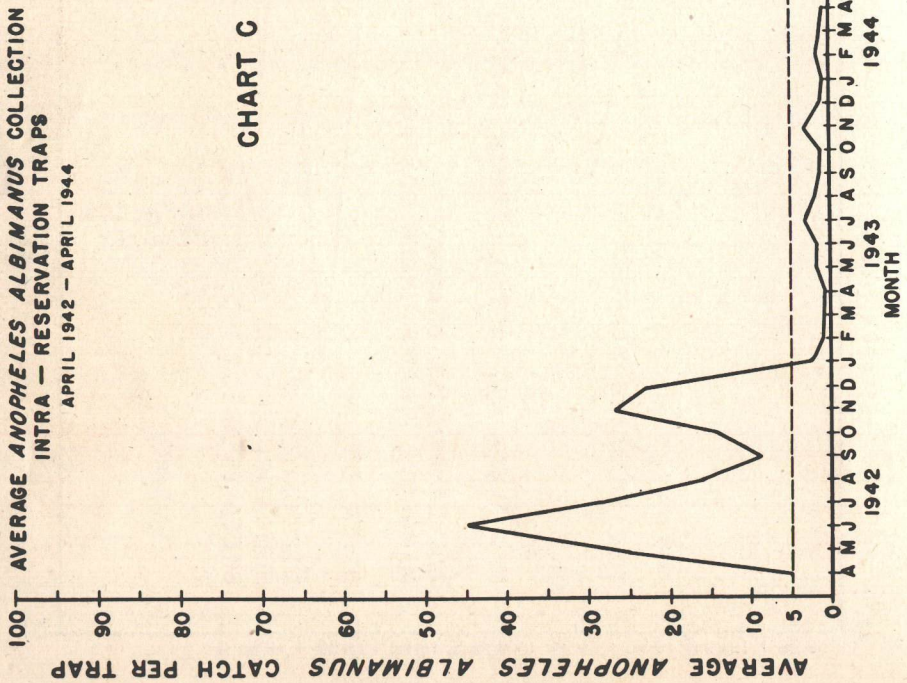


CHART C
AVERAGE ANOPHELES ALBIMANUS COLLECTION
INTRA — RESERVATION TRAPS
APRIL 1942 — APRIL 1944
AVERAGE ANOPHELES ALBIMANUS CATCH PER TRAP
100
90
80
70
60
50
40
30
20
10
5
0
A M J J A S O N D J F M A M J J A S O N D J F M A
1942
1943
1944
MONTH

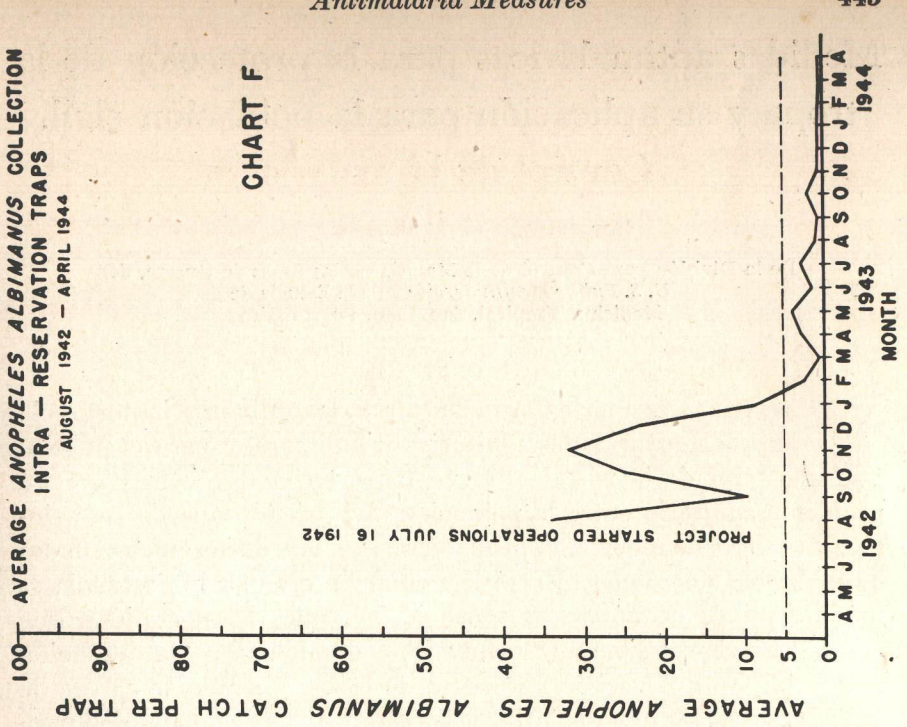


CHART F
AVERAGE ANOPHELES ALBIMANUS COLLECTION
INTRA — RESERVATION TRAPS
AUGUST 1942 — APRIL 1944
PROJECT STARTED OPERATIONS JULY 16 1942
AVERAGE ANOPHELES ALBIMANUS CATCH PER TRAP
100
90
80
70
60
50
40
30
20
10
5
0
A M J J A S O N D J F M A M J J A S O N D J F M A
1942
1943
1944
MONTH

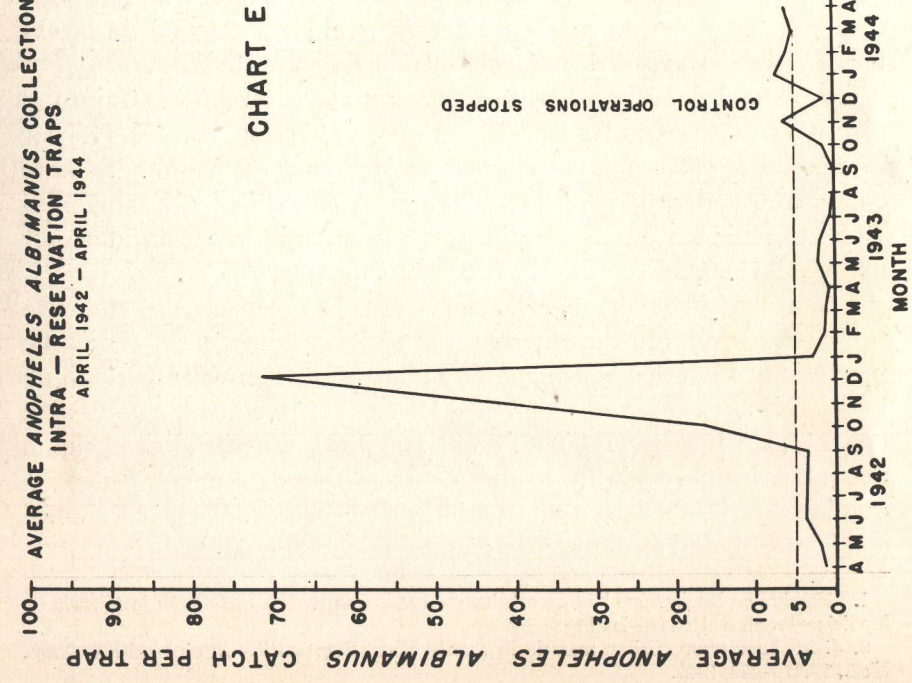


CHART E
AVERAGE ANOPHELES ALBIMANUS COLLECTION
INTRA — RESERVATION TRAPS
APRIL 1942 — APRIL 1944
CONTROL OPERATIONS STOPPED
AVERAGE ANOPHELES ALBIMANUS CATCH PER TRAP
100
90
80
70
60
50
40
30
20
10
5
0
A M J J A S O N D J F M A M J J A S O N D J F M A
1942
1943
1944
MONTH